Enhanced Heat Transfer, 1999, Vol. 6, pp. 71–78
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Ralph L. Webb: A Pioneering Proselytizer for Enhanced Heat Transfer

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(Received 30 October 1998)

Ralph Webb, a pioneer in enhanced heat transfer, proselytizes his field for the economic and technical benefit of industry. His mission has been, and always will be, the promotion of enhanced heat transfer technology. As a result, he has been instrumental in facilitating the industrial use of augmentation in innovative heat exchanger design.

Ralph L. Webb, 1999

INTRODUCTION

Dr. Ralph Lee Webb is currently a Professor of Mechanical Engineering at The Pennsylvania State University. Much of Ralph's research focuses on the refrigeration and air-conditioning, automotive, computer, electronic equipment, and the electric power generation industries. The commercial use of enhanced heat transfer surfaces in the evaporators and condensers of residential and commercial air-conditioning equipment is a principal factor contributing to large energy efficiency improvements in products since 1975. Ralph's work on enhanced heat transfer has made key contributions to these technological improvements.

From 1963–1978, Ralph was Manager of Heat Transfer Research at The Trane Co. where he employed enhancement technology to improve energy efficiency of the company's air-conditioning equipment. He joined The Pennsylvania State

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University in 1978 where he continued his work on enhanced heat transfer and expanded his research to other industrial applications. Ralph has worked to make industrial engineers aware of the energy saving benefits of "enhanced heat transfer technology." He teaches a number of professional short courses and an academic course on enhanced heat transfer. In addition to research publications, Ralph advocates the benefits of enhanced heat transfer in book and handbook publications. He is author of the book, *Principles of Enhanced Heat Transfer*, published by Wiley Interscience in 1994. This book provides detailed descriptions of the technology, applications, benefits, and design methods. The book provides design guidance, promotes the industrial use of enhanced heat transfer, and guides researchers in future needs. In addition, Ralph is founding editor of the *Journal of Enhanced Heat Transfer*. This international journal provides a worldwide forum for the basic and applied technology of enhanced heat transfer.

Ralph's research interests include boiling, condensation, absorption, and single phase convection to gases and liquids. He has also done a significant amount of work on evaporative heat exchangers (*e.g.*, cooling towers and dehumidifying heat exchangers).

His key contributions include analytically based models for heat transfer and friction in the enhanced surface geometries, development of innovative heat exchanger technology, and U.S. Patents.

THE EARLY YEARS

Ralph Lee Webb was born on February 22, 1934 in Parker, Kansas in the northwest bedroom of the family's farmhouse. Ralph's mother, Grace, labored for eight hours before giving birth to Ralph. Parker, Kansas, as the rest of the country, was in the middle of the Great Depression. Despite the hard times, Ralph's father, Kenneth, was able to sell one of the sheep to pay old Doc Warner the $25 delivery fee. Kenneth and Grace worked the windy farm until 1938 when Kenneth put farming aside (for a few years) and went to work in the oil fields of Illinois to be able to put bread on the table.

In 1948, Ralph worked at the local drive-in-movie theater washing windshields for tips. Westerns and War movies were popular then. For the most part, with the exception of one night, the shooting remained confined to the big screen. The 14-year-old Ralph looked up to an older and wilder friend named Clark who was 16 years old, full of imagination, and had access to a 0.32 caliber pistol. One night, this spelled trouble for Ralph: Clark shot him in the side while play-acting. Ralph fell to the floor and said, "You got me, Clark. Take me to the hospital," not thinking that he could possibly die from this wound. The immortality of youth gave Ralph no sense that he was in very grave danger. Fortunately, three fates favored Ralph that night. First, the owner of the drive-in had enough sense to drive Ralph directly to the hospital where they found that the bullet had severed his aorta. If they had waited for an ambulance to take him to the hospital, he surely would have died from loss of blood. Ralph's second great fortune was that his physician was an experienced World War II surgeon who was familiar with combat wounds. The surgeon repaired Ralph's aorta but was unable to recover the slug, which remains in his side. To complete the triad of fortune, penicillin had just been invented. Ralph required 256 penicillin shots to kill the peritonitus.

Ralph survived the gun shot wound to graduate from high school and enter Kansas State University. He graduated with honors in 1957 with his Bachelor's degree in Mechanical Engineering. After graduation, Ralph remained at the University for a semester as an instructor of Mechanical Engineering. The next two years found Ralph working as an Engineering Maintenance Officer for the U.S. Air Force at the Nellis Air Force Base in Nevada – Las Vegas! He then accepted a position as an experimental engineer at the Knolls Atomic Power Laboratory (KAPL) in Schenectady, New York. Here, Ralph began to hone his expertise in designing heat transfer test sections. He designed

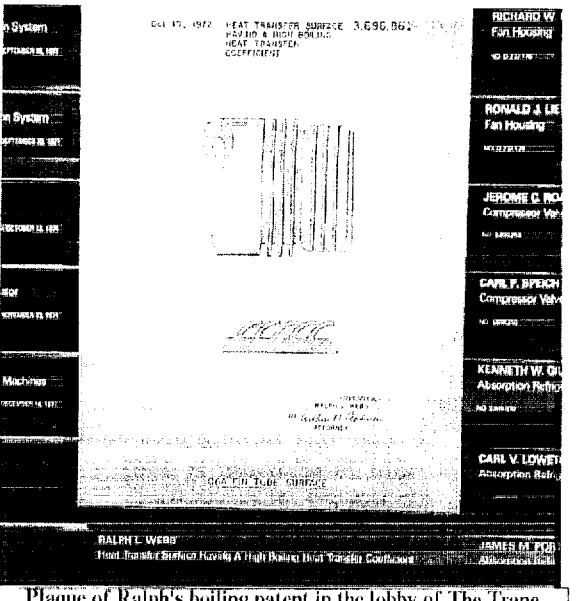
had existed before the turn of the century, industry's use of it in the early 1960s was very limited. Ralph's Ph.D. thesis was one of many first "ice breakers" that he developed to get industry seriously interested in enhanced heat transfer. He did this by providing industry with the tools that they required to evaluate and design heat exchangers with enhanced geometries.

For his thesis, Ralph developed a semi-analytical model to predict the heat transfer coefficient for forced convection in tubes with "transverse-rib" roughness. His original model accounted for the effects of roughness dimensions and Prandtl number. The work later broadened to include the effects of rib shape and helix angle. This shows one of the first examples where Ralph's work provided industry with the fundamental tools needed to design and evaluate enhanced heat exchangers, *e.g.*, water chiller evaporators having internally rough tubes. Wolverine Tube used Ralph's Ph.D. model to develop internal "helical-rib" roughnesses. Today, the helical-rib roughness is the workhorse for enhancing the water-side performance of flooded refrigerant condensers and evaporators.

Under Ralph's supervision at Trane, the "three-dimensional wavy fin" was developed for finned tube heat exchangers. This fin geometry has been used commercially in unitary air conditioning and heat pumps since 1969. The fin geometry provides a 100% higher air-side conductance than that of a plain fin.

Ralph also developed an enhanced boiling surface geometry for shell-side boiling in flooded refrigerant evaporators. He received two U.S. Patents for this work, and Trane commercialized the geometry in 1971. This was the first commercially practical nucleate boiling enhancement globally used in the refrigeration industry. It is still used today. A plaque of the Patent is proudly displayed in Trane's lobby in La Crosse and is highlighted with a sketch of the device.

A second Patent came from Ralph's research into a means to enhance film absorption of steam in aqueous lithium bromide flowing over a bundle of horizontal tubes. The work resulted in a unique "spine-fin" geometry that provides surface tension induced mixing of the liquid film *via* local "cold spots" at the spine locations. This work resulted in a 1980 U.S. Patent.



Plaque of Ralph's boiling patent in the lobby of The Trane Co., La Crosse, WI (courtesy of S. Moeykens & The Trane Co.)

ASME HEAT TRANSFER DIVISION

Ralph became active in the American Society of Mechanical Engineers (ASME) in 1966 when he joined the K-8 Committee of the Heat Transfer Division – the committee on Theory and Fundamental Research. This committee helped him to direct his work at Trane. He remained on the committee for eight years.

Ralph and Professor Arthur Bergles met and first worked together in 1970 in connection with the development of a session at the 1971 ASME Winter Annual Meeting on Augmentation of Heat Transfer. This was a special publication that pre-dated the current numbered series of Heat Transfer Division publications. They subsequently teamed up for eight ASME courses on the subject,

tests to simulate the heat flux distribution in a nuclear reactor to establish the critical heat flux. While he was in KAPL, he attended the Rensselaer Polytechnic Institute and earned his Masters in Mechanical Engineering in 1962. After graduation, Ralph accepted a Fellowship for graduate study at the University of Minnesota, where he took graduate studies for one year.

THE TRANE COMPANY

While Ralph was at the University of Minnesota, The Trane Company asked him to join their newly formed Applied Research Group. After much soul searching, the challenge and excitement of the Trane offer enticed Ralph enough for him to temporarily suspend his Ph.D. studies and join the group. Although his hair was turning prematurely grey, Ralph was only 29 years-old in 1963, so he was viewed as not being sufficiently "seasoned" to be given the key position as heat transfer group leader at that time. However, the position was promised to him if he could prove himself in his new job. Ralph must have impressed the upper management because two years after joining Trane, he was promoted to Manager of Heat Transfer Research. In the following years, Ralph continued to have success which fueled the expansion of the heat transfer section to include nine people.

As manager, Ralph was responsible for two main areas: (1) conception and evaluation of high performance heat transfer surfaces and innovative heat transfer concepts, and (2) technological development of product concepts which involved technology new to Trane. In addition, Ralph and his group evaluated emerging technologies and recommended corporate policy (*e.g.*, solar energy, and future energy costs). They worked in virtually all aspects of convective heat transfer, boiling, condensation, and simultaneous heat-mass transfer.

The corporate ambiance at Trane in the 60's and 70's was white shirt, dark tie, cleanly shaven face and short hair. Despite Ralph's individualism, Trane and Ralph had a mutually beneficial 14 years together. Trane higher-ups tolerated his desire to ride his motor scooter (with safety helmet) to work and even to grow a mustache. Even a painting of "two Chinese scholars in intense study" was permitted in Ralph's office.

One of Ralph's rich experiences at Trane was the opportunity to work with Professor E. R. G. Eckert, who served as a consultant to Trane for 12 years during Ralph's tenure. Although Professor Eckert was Ralph's Ph.D. Advisor, he spent much more time with Professor Eckert during the monthly consulting visits at Trane than was possible at the University. This extensive interaction with Professor Eckert greatly influenced Ralph's professional development and was crucial for the completion of his Ph.D.

Both Trane Vice-President H. Corbyn Rooks and Professor Eckert saw potential in the young man from Kansas and encouraged him to finish his Ph.D. at the University of Minnesota. Ralph spent one semester in residence at Minnesota finishing his Ph.D. course work, and then spent many hours, while working at Trane in LaCrosse, studying for the German and French language exams. He selected his Ph.D. thesis topic and did his preparatory thesis work while on the job in LaCrosse. Because of Prof. Eckert's monthly consulting visits, Ralph worked closely with Prof. Eckert on his thesis topic while at Trane. This work also included building his experimental apparatus in the Trane machine shop. When that was done, he rented a truck and hauled the apparatus to Minnesota, where he and his wife and two young children lived for the next year while he finished the thesis. Finally, after long days as Manager and long nights as Ph.D. Candidate, Ralph earned his doctorate in Mechanical Engineering from the University of Minnesota in 1969.

Professor Eckert and Professor Goldstein jointly advised Ralph on his thesis topic, which would become the authoritative reference in correlating friction and heat transfer roughness data. Although the concept of enhanced heat transfer

formulated a theoretical model to predict the condensation coefficient of any refrigerant on integral-fin tubes of any fin spacing, height, and fin shape. He has also studied the "row effect" of condensation on a bank of horizontal, enhanced tubes, for various enhancement geometries. Ralph's condensation research has given us 20 papers in journals and two book chapters.

Ralph received the "1985 Journal Best Paper Award" from the ASHRAE Journal for his work on the thermal design theory of evaporative heat exchangers. This is a "unified theory" that applies to the design of cooling towers, evaporative fluid coolers, and evaporative condensers. Ralph has improved this work by creating an "exact" theoretical formulation for evaporative heat exchangers, which reveals the errors associated with the use of the "Merkel approximation." The improvement involves the crossflow and counterflow effectiveness-NTU equations for cooling tower design. It allows a person competent in heat exchanger design to easily design cooling towers.

A new research interest of Ralph's is cooling of electronic equipment. Currently, he is working with a Japanese heat sink manufacturer and U.S. computer makers to introduce innovations in cooling of notebook and desktop computers.

Ralph once told me that the relationship between a professor and a graduate student is similar to courtship and marriage. Both parties must want to enter into the relationship and be willing to seek common ground. I know that Ralph believes this and treats his graduate students like family. The graduate student/professor relationship is very important to him. As an advisor, Ralph provides direction and recommendations. He does not dictate a course of action to the student. Ralph allows the students to grow to their own potential. He says "When the day of your thesis defense arrives, this should be your work – not mine".

He is an avid collector of photos of his former graduate students' children and loves to show them to his "alumni." After graduation, the student becomes a member of Ralph's "extended family". Many former students (and their children) visit Ralph, his artist wife Sylvia, and their Scottish Terrier (Fergus), who now live in the country, 10 miles from State College, Pennsylvania. A list of his extended family members is given in the Graduate Thesis Supervised Section.

Ralph practicing to hood the author before the graduation ceremony

PRINCIPLES OF ENHANCED HEAT TRANSFER, R. L. WEBB, WILEY INTERSCIENCE, 1994

Ralph had spent more than 35 years writing and collecting papers on enhanced heat transfer. He felt that he must pass this knowledge on to the "new generation" before hanging up his sword and shield. He hopes that the book will serve to advance the field from an empirical subject to one that is rationally based. Now, he is collecting materials for the 2nd edition, which he hopes to work on in the year 2000!

GRADUATE THESES SUPERVISED

Ph.D. Degrees (15 total)
Amar S. Wanni, Dec. 1980
Thomas M. Rudy, Dec. 1982
Himanshu M. Joshi, Jan. 1985
Mark A. Kedzierski, Dec. 1987

as well as two courses in industry. The most recent of these was at the 1996 National Heat Transfer Conference in Houston. One of the industrial offerings was the first European course sponsored by Wieland in Ulm, Germany. Ralph and Art also "conspired"- as Art says – over the years on over a dozen papers and reports. The object of these activities, in Ralph's words, was to "proselytize enhanced heat transfer." Art says, "In traveling to our meetings, our biggest challenge was to get the numerous samples of enhanced surfaces through the metal detectors at airports!" These experiences have created a lasting friendship between Ralph and Art.

Ralph was Technical Editor of the *Journal of Heat Transfer* from 1972 to 1976. This helped to prepare him for the Chairmanship of the Heat Transfer Division which he held in 1979.

PENN STATE

In 1976 The Pennsylvania State University established a search committee to find a strong candidate to add to their thermal sciences faculty. In 1977, Ralph accepted a position as Associate Professor of Mechanical Engineering at Penn State. He was promoted to full Professor in 1981.

In the early Penn State years, Ralph began developing the Performance Evaluation Criteria (PEC) analysis. The PEC analysis is a key element for the utilization and promotion of enhanced heat transfer technology. Without PEC, it would be difficult to sort through many possible enhancements. The PEC analysis is an essential part of Ralph's proselytization of enhanced heat transfer. It helps the heat exchanger designer to determine the best enhancement based on specific design criteria such as pumping power and heat exchanger length requirements.

Ralph has never lost sight of the real goal of all this enhanced heat transfer technology: to actually use it to design and build optimized heat exchangers. His career at Penn State has been devoted to working with industry to find better ways to transfer heat. Ralph's devotion has resulted in continuous industrial sponsorship of his research and commercialization of the technology that he has advocated. A good example of his drive to produce useful tools for industry is his work on gas-cooled brazed aluminum heat exchangers. Here, he has developed equations to predict the heat transfer coefficient and friction factor based on the geometric parameters of this type of heat exchanger. Ralph provides direction in 33 publications to define preferred surface geometries for industrial applications, including cryogenic and combustion heat recovery exchangers. The publications are found in journals and books including a 62 page chapter "Enhancement of Single Phase Heat Transfer" in the Handbook of Single Phase Heat Transfer, (Wiley, 1988) and two chapters on "compact heat exchangers" in the *Handbook of Heat Exchanger Design* (Hemisphere, 1982).

Ralph has responded to industry's needs by filling the gaps in research. For example, virtually nothing was known about the fouling characteristics of internally enhanced tubes for water cooled evaporators and condensers until he set out and explored this area. Among this work, Ralph has conducted significant fouling measurements of commercial enhanced tubes in both accelerated (short term) and long term fouling tests. His fouling research also includes the evaluation of "on-line" fouling control, *e.g.*, flow driven brushes to clean the enhanced tubes during operation. Ralph has supported commercial enhanced tube manufacturers with his research to identify enhancement geometries that are least susceptible to performance degradation due to fouling.

Another area in which Ralph has focused on filling in the research gaps is refrigerant condensation. Since 1979, Ralph has theoretically and experimentally researched condensation on horizontal, integral-fin tubes to guide industry to preferred enhancements. His work was the first to show that condensate is retained in the interfin region as a result of surface-tension forces, and that surface tension, rather than gravity forces, causes drainage of the condensate from the fins. Ralph has

Nae-Hyun Kim, December 1989
M. Hassib Jaber, Aug. 1991
Neelkanth Gupte, Jan. 1992
Louay Chamra, Aug. 1992
Tamarisa Apparao, Jan. 1993
Imam Haider, Jan. 1994
Chien-Yuh. Yang, Jan. 1995
Liang-Han Chien, Aug. 1996
Kwang-Taek Hong, Dec. 1996
Ming Zhang, May 1998
Wei Li, August 1998

Masters Degrees (39 total)
Dennis Gee, Aug. 1979
Margaret Scott, Jun. 1980
Santosh Keswani, Oct. 1980
J. S. Hong, November 1981
Prakash Chandra, Dec. 1982
David Burrichter, May 1982
David Marchiori, Jan. 1983
Robert Durbin, August 1982
Allejandro Villacres, May 1984
Petur Thors, May 1984
Mark A. Kedzierski, May 1985
Key-Dong Choi, Jun. 1986
Tim A. Burkett, January 1986
Wen Yu, Jun. 1986
Mark DiGiovanni, Jun. 1986
Paul Trauger, Jun. 1988
Christopher Murawski, Jun. 1988
James Bogart, Jan. 1989
Paul Farrell, Jan. 1990
Christopher Pais, Jan. 1990
Abdeljalil Sahnoun, Jun. 1991
Sung-Han Jung, Jan 1992
Bill McQuade, Jan. 1993
Eric Dillen, May 1993
Abdeljalil Sahnoun, May 1992
Kalyan Mukherjee, May 1994
Larry Scherer, August 1994
Kwang-Taek Hong, May 1995
Laurent Brognaux, Aug. 1995
Wei Li, Jan. 1996
Hirofumi Hirouchi, Dec. 1996
Kevin Moser, Jun. 1997
Li-Peng Wang, Dec. 1997
Ajay Iyengar, Dec. 1997
Wei Li, May 1998
Vladimer Zarnescu, Jan. 1998
Mehmet Koseoglu, June 1998
Koichiro Take, Dec. 1998
Ram Narayanamurthy, Dec. 1998

Post Doctoral & Visiting Scholars (10 total)
Prof. Thomas Adamek, Stuttgart Univ., 1987
Louay Chamra, Penn State, 1996
Gyurak Kim, LG Electronics, 1996
Liang-Han Chien, Penn State, 1997
Prof. Hie-Chan Kang, Kunsan Univ., 1997
Hyunuk Lee, LG Electronics, 1997
Jing-Chun Min, China, 1997–99
Davide Del Col, Padova Univ. 1998
Kemal Ermis, Sakarya Univ., 1998
Je-Young Chang, Research Assoc., 1988–89

CONCLUSION

In 1993, Ralph founded the *Journal of Enhanced Heat Transfer*. This biography is part of a special issue of the Journal in tribute to Professor Ralph Lee Webb on his 65th birthday. Professor Ralph Webb has certainly been a pioneer in the field of enhanced heat transfer. Many of the enhancements that are used, and the way that we all think about enhanced heat transfer, have Ralph's fingerprint on them. Rolling up his sleeves and working on an experiment or on a theory is in his being. Ralph is driven. Consequently, it is easy to say that we will all continue to benefit from Ralph's constant promotion of enhanced heat transfer technology. After all, he is the original proselytizer for enhanced heat transfer.

Acknowledgements

The author would like to thank Professors Arthur Bergles, Ernest Eckert, Richard Goldstein and

Ralph Webb for their help in writing this manuscript. Also, special thanks goes to Dr. Shane Moeykens and the Trane Company for taking the photo of Ralph's patent. Thanks to Mrs. Janet Land, Mrs. Wendy Kedzierski, Dr. Raj Manglik, Dr. Vance Payne, and Dr. Amar Wanni for their valuable editorial comments.

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Webb, R. L. (1994) *Principles of Enhanced Heat Transfer*, John Wiley & Sons, New York.